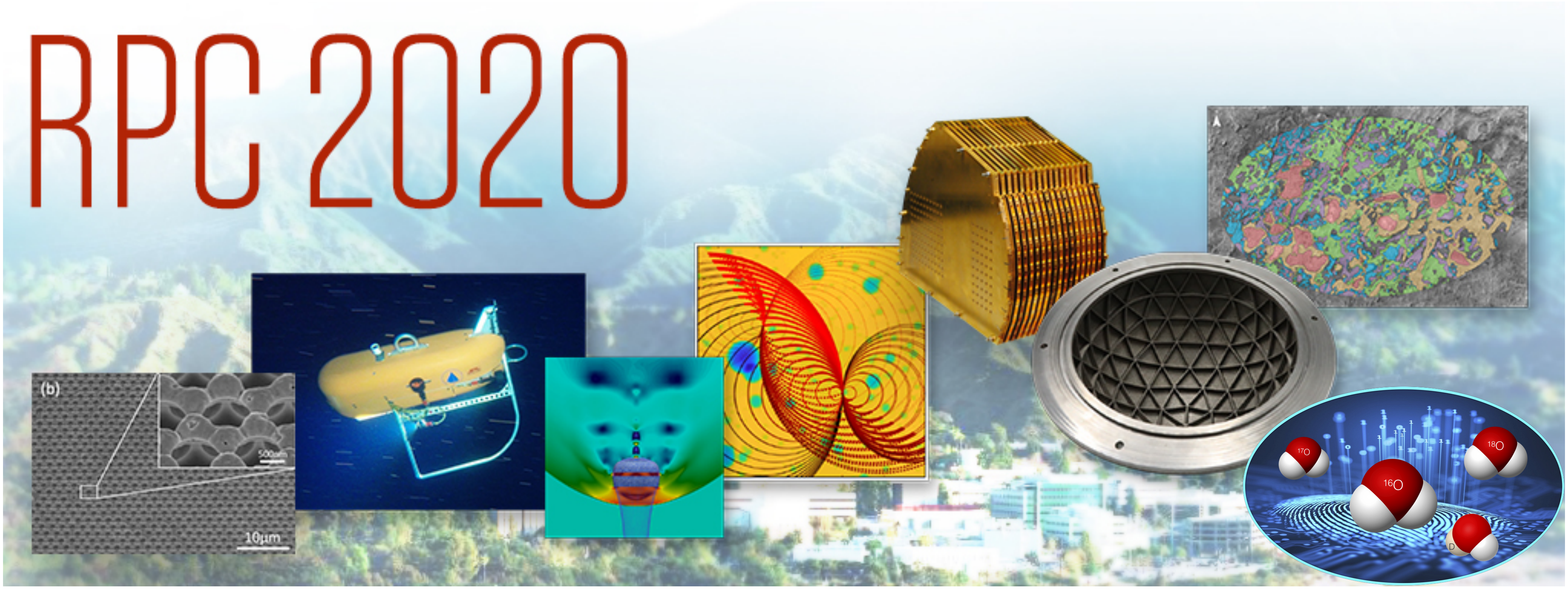

Virtual Research Presentation Conference

Tracing Water from Interstellar Clouds to Ocean Worlds

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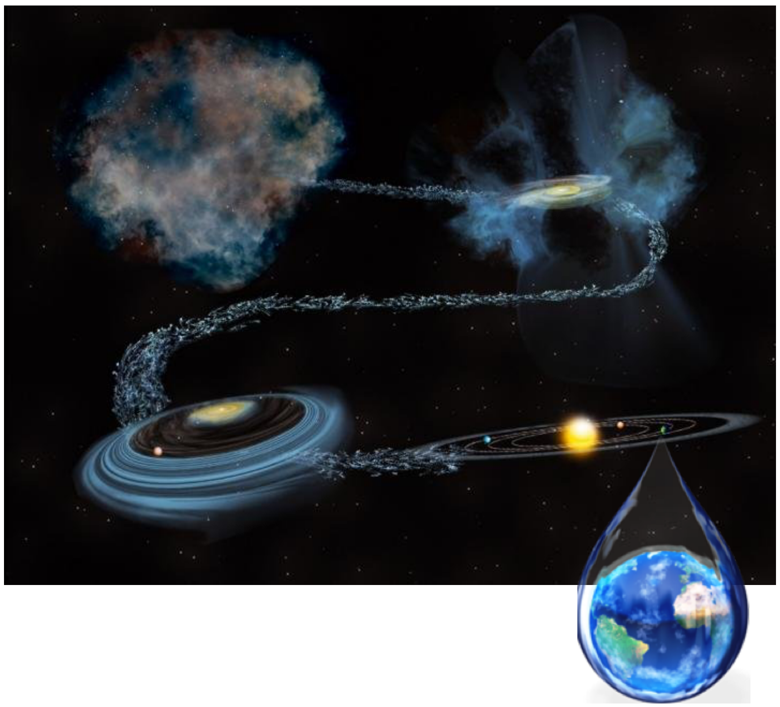
Program: Strategic Initiative
Assigned Presentation # RPC-005

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction



Credit: Bill Saxton, NRAO

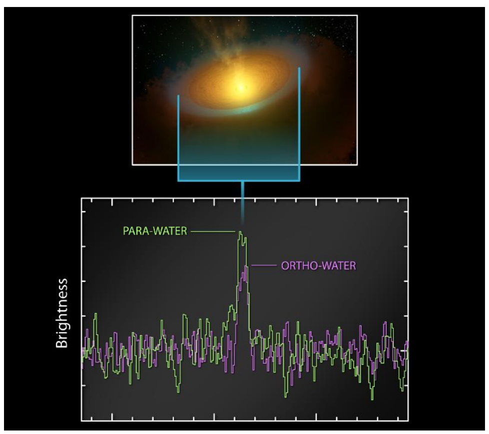
Abstract

Understanding how the Earth obtained its water and whether water-rich Earth-like planets are common in the Universe is a central theme in NASA's vision. Water, a key ingredient for life, forms efficiently on cold dust grains and is abundant in interstellar clouds. Whether there are universal pathways leading from this vast interstellar reservoir of water to forming planetary systems, and whether the Solar System water content is representative of other systems is a less understood aspect.

The trail of water throughout all stages of star and planet formation can be followed spectroscopically, using the deuterium/hydrogen isotopic ratio, a critically important tracer of the thermal history of the gas. This can be accomplished with a large, 3-m class, FIR telescope equipped with a cryogenically cooled heterodyne instrument that covers the key isotopic water lines in the 450-600 GHz frequency range.

Water isotopic ratios in atmospheres of Solar System small bodies, such as comets, which contain some of the most pristine materials from the protosolar disk, can also be investigated with inexpensive smallsat missions carrying passively cooled heterodyne instruments. Such a candidate SIMPLEx mission concept has been developed within the framework of this SRTD.

Problem Description



Herschel observations of water emission in the disk of TW Hydrae.

Herschel Space Observatory firmly established the importance of water in planet formation. Water emission and absorption was detected in a prestellar core, 3 disks, and dwarf planet Ceres. The D/H ratio was measured in 4 protostars and 3 comets.

SOFIA/4GREAT can now measure the D/H ratio in very bright comets and ALMA can measure D/H in warm water vapor in protostars. JWST will provide complementary information by observing hot water vapor close to the star and measuring D/H in ice in moderate extinction regions, in absorption toward background stars.

However, the bulk of water vapor is cold, and low-energy water transitions can only be observed from space. A dedicated spectroscopic space mission is thus needed to fully address science of water in a statistically significant way.

"*Building new worlds*", specifically "*What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets*" has been identified as one of the broad crosscutting science themes by the Planetary Science Decadal Survey *Vision and Voyages*. Our SRTD directly addresses this science theme, as well as the JPL quests "*Understanding how our Solar System formed and how it is evolving*", and "*Understand how life emerged on Earth and possibly elsewhere in the Solar System.*"

Our long-term objective is to enable future JPL spectroscopic missions ranging from SIMPLEx concepts, to larger Discovery or Explorer class missions. A heterodyne instrument for the next NASA FIR flagship (such as *Origins*) is another exciting opportunity.

Methodology

Isotopic ratios in Solar System comets can be measured with an inexpensive smallsat mission. Such a mission concept, *Wisper*, is currently studied by 4X as a candidate for the SIMPLEx 3 AO expected in 2021.

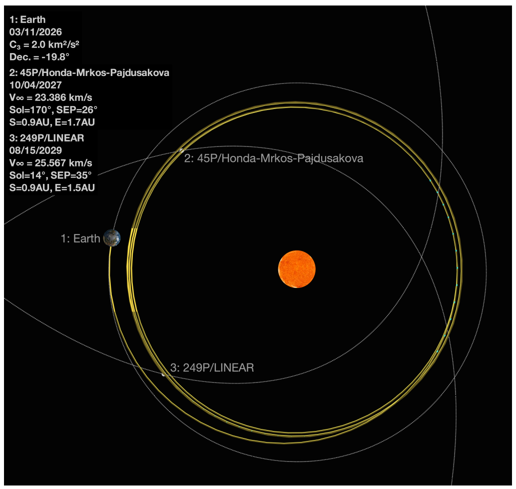
Wisper is a smallsat on an escape trajectory, with propulsion, to make a close encounter with the hyperactive comet 45P/Honda-Mrkos-Pajdusakova in 2027 at 0.9 au from the Sun.

Wisper uses a passively cooled Schottky heterodyne spectrometer to observe spectroscopic signatures of $H_2{}^{16}O$, $H_2{}^{17}O$, $H_2{}^{18}O$, and HDO in the 509-557 GHz frequency range. Wisper builds upon the heritage of *Rosetta*/MIRO, providing a factor of 3 improvement in sensitivity.

Wisper science objectives are:

- Determine whether oxygen isotopic ratios in water in a hyperactive comet follow mass-independent fractionation patterns found in inner Solar System materials, confirming that water is the main carrier of oxygen.
- Confirm the anticorrelation between hyperactivity and the D/H ratio in comets, revealing the presence of a vast reservoir of ocean-like water in the outer Solar System.

Results



Current Wisper trajectory including an encounter of comet 45P as a baseline mission and a second encounter of comet 249P as a possible target of an extended mission.

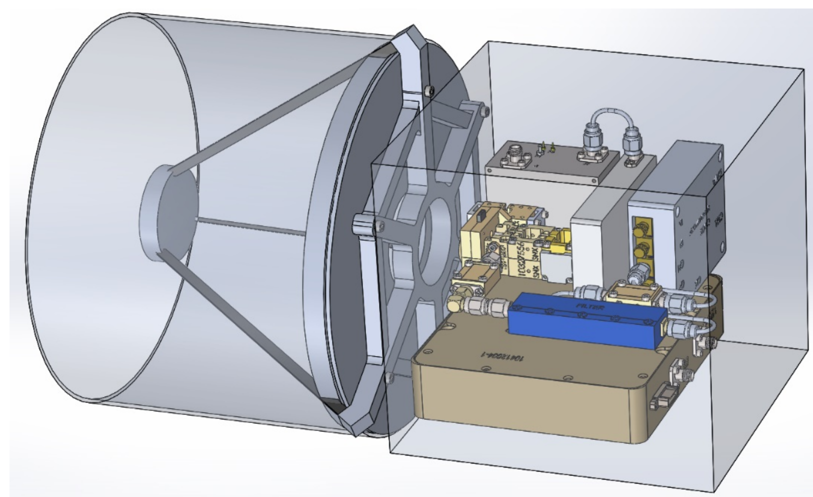
During FY20, we have been developing the *Wisper* science case and building a science team including partners from U. Michigan (E. Bergin), U. Hawaii (K. Meech), and CNES/LESIA (D. Bockelée-Morvan and N. Biver).

Following an RFI to the industry, several possible spacecrafts have been identified.

Work on the detailed design of the submillimeter instrument is ongoing.

Wisper has completed the Team-X Architecture Study and is currently preparing for a Portfolio Gate Review.

The goal for FY21 is to fully develop the concept, leading to a mission proposal in response to the SIMPLEx 3 AO expected in the Spring of 2021.



Current Wisper instrument design with a 20 cm antenna and a passively cooled Schottky heterodyne receiver.

Publications (FY20)

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- J.W. Kooi, D.J. Hayton, P.F. Goldsmith, et al. “*Dual Local Oscillator SIS Receiver for Simultaneous Observations of Water Isotopologues in the Solar System.*” Submitted to *IEEE Trans. Terahertz Science and Technology.*
- E.F. van Dischoeck, L.E. Kristensen, J.C. Mottran, et al. “*Water in Star-Forming Regions: Physics and Chemistry from Clouds to Disks as Probed by Herschel Spectroscopy.*” Submitted to *A&A*.
- J.W. Kooi, D.J. Hayton, B. Bumble, et al “*Quantum Limited SIS Receiver Technology for the Detection of Water Isotopologue Emission from Comets*.” To appear *in IEEE Trans. Terahertz Science and Technology*, 2020.
- E. Murchikova, E.J. Murphy, D.C. Lis, et al. “*Reconstructing EUV spectrum of star forming regions from millimeter recombination lines of H I, He I, and He II.*” *Ap.J.*, in press, arXiv:2006.15153.
- L. Wanggi, F. Nakamura, B. Wu, et al. “*Star cluster formation in Orion A.*” *PASJ*, doi:10.1093/pasj/psaa035 (2020/05).
- M.A. Cordiner, S.N. Milam, N. Biver, et al. “*Unusually high CO abundance of the active interstellar comet*.” *Nature Astronomy*, **4**, 861 (2020/04).
- G. Melnick, V. Tolls, R.L. Snell, et al. “*Distribution of Water Vapor in Molecular Clouds. II*” *Ap. J.*, **892**, 22 (2020/03).
- D.C. Lis, T. Putaud, X. Michaud, et al. “*Ortho-Para Ratio in Water in the Interstellar Medium*.” *AAS*, **23526104L** (2020/01; AAS Meeting).
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- T. Putaud, X. Michaut, F. Le Petit, et al. “*The water line emission and ortho-to-para ratio in the Orion Bar photon-dominated region*.” *A&A*, **632**, 8 (2019/12).